A Proposal to the

Office of Naval Research

Special Program in Acoustic Reverberation

by

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JUNE 1995

DISTRIBUTION STATEMENT A
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for

Ocean Bottom/Subbottom Seismic-Acoustic Scattering With Realistic Sediment Properties

Proposed Date:	10/1/89 - 9/30/91
Project Duration:	24 months
Amount Requested:	$252,373

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DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
SEATTLE REGIONAL OFFICE
1107 NE 45TH STREET, SUITE 350
SEATTLE WA 98105-4631

IN REPLY REFER TO:

4330
ONR 247
11 Jul 97

From: Director, Office of Naval Research, Seattle Regional Office, 1107 NE 45th St., Suite 350, Seattle, WA 98105

To: Defense Technical Center, Attn: P. Mawby, 8725 John J. Kingman Rd., Suite 0944, Ft. Belvoir, VA 22060-6218

Subj: RETURNED GRANTEE/CONTRACTOR TECHNICAL REPORTS

1. This confirms our conversations of 27 Feb 97 and 11 Jul 97. Enclosed are a number of technical reports which were returned to our agency for lack of clear distribution availability statement. This confirms that all reports are unclassified and are "APPROVED FOR PUBLIC RELEASE" with no restrictions.

2. Please contact me if you require additional information. My e-mail is *silverr@onr.navy.mil* and my phone is (206) 625-3196.

ROBERT J. SILVERMAN

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Abstract

This proposal addresses two related aspects of the acoustic reverberation problem, namely (1) seismic-acoustic properties of ocean bottom/subbottom sediments, and (2) the short-range scattering of acoustic/elastic waves at the rough and heterogeneous bottom/subbottom interface zone. The primary objective of the proposed research is to quantify the importance of bottom/subbottom scattering of compressional and converted shear waves. The approach is to numerically simulate short-range scattering using realistic models for the geometry, scales, and vertical and lateral variations in material properties of the ocean bottom and especially subbottom. To treat this problem realistically, a numerical model for constrained sedimentological deposition of sands and clays over basement rock is used to describe the three-dimensional geometry of sediment beds and laminae over basement rock. Models for rock properties are then used to determine the seismic velocity, attenuation, density, porosity, and permeability for the suspended and loosely consolidated granular sediment materials and basement rocks. This geological model is then used in three-dimensional seismic-acoustic simulators to predict the acoustic fields scattered by the rocks at and below the interface. Two preliminary finding of results by us to date are noteworthy: First, acoustic scattering is completely inadequate for describing the interaction, particularly near grazing angles where the elastic boundary conditions play a critical role in establishing the energy balance. Second, bathymetrically "smooth" surfaces may be acoustically very "rough", providing a mechanism for the "anomalous" scattering regions observed in reverberation data and the importance of subsurface scattering in the reverberation problem. Our simulation codes are implemented on a dedicated in-house supercomputer, thus providing a powerful and cost effective computer platform for performing the proposed research.

1.0 Science Statement and Research Goals

For purposes of describing the reverberant acoustic wavefield in the ocean column, the seismic-acoustic scattering phenomena at the bottom/subbottom interface can be conveniently divided into two range-scale dependent regimes: (1) short-range (several tens of wavelengths) interactions at the bottom/subbottom interface, e.g., scattering zones, and (2) long-range (hundreds of kilometers) interactions among spatially distributed scattering zones. In this proposal we address the short-range scattering phenomena using 2D and 3D numerical simulators of scattering from realistic geological models for ocean bottom/subbottom sediments.

Preliminary research in this area performed in our group (Samec and Marion, 1989) has revealed two important physical phenomena related to sea floor scattering. First, we find that a heterogeneous shear transition zone, where the shear velocity increases slowly from zero to some finite value, must exist between the water and the compacted sediments. Acoustic waves penetrating the bottom are continuously scattered in this zone with some energy being converted to downgoing forward scattered shear waves. In a similar way, distributed scattering of upgoing compressional and shear waves, e.g., reflected from basement rocks, generate upgoing compressional energy which reenters the ocean column and contributes to the reverberant acoustic field. It is therefore critically important to consider the full elastic scattering which includes shear waves if the scattered energy balance is to be quantitatively determined.

The second important observation from our preliminary study is that a bathymetrically "smooth" surface, as generated by the SedSim depositional model described below, can appear very "rough" to the illuminating acoustic wavefield. This effect depends on the history of deposition and compaction of the sediments, the frequency of the acoustic waves, the angle of incidence of the acoustic wavefield, and of course, the material properties and the spatial variability of the sediments. The question arises as to whether this effect is partially responsible or important for explaining the anomalous zones called "phantoms" which are often observed in real reverberation data.

The observations summarized above were made using 2D geological elastic models. The questions raised in the SRP announcement and subsequent planning meetings can only be answered with realistic geological and seismic-acoustic models - three-dimensional anelastic scattering from realistic geological models not only with rough water bottom but also with subbottom heterogeneities.

The primary goal of the proposed research is to quantitatively describe the importance of short-range bottom/subbottom scattering of compressional and shear waves on the compressional wave energy reentering the ocean column. This research has ~~two~~ 3 distinct components:

(1) Realistic geological modeling to describe the rough interface and subbottom volume heterogeneities and rock physics modeling to describe material properties of the sediments.

(2) Seismic-acoustic modeling to identify the role of subbottom scattering on the acoustic energy balance, closely examining the influence of shear waves and attenuation.

(3) Statistical analysis of the short-range scattered fields for use in long-range reverberation models.

2.0 Research Approach and Preliminary Results

2.1 Technical Approach

A significant effort is already underway in our research groups in areas of numerical modeling of seismic scattering in heterogeneous media. A variety of techniques with working computer codes are in place. These include 3D ray tracers with parabolic approximations, gaussian beams, and full wave solvers using finite differences, finite elements, and hybrid techniques. Research is being started on boundary element methods. This ongoing research has mostly been directed at and funded by exploration and development applications for oil and gas. We propose to adapt the existing 2D and 3D full wave seismic modeling codes, e.g., FE, FD, and Hybrids, to the problem of short-range scattering from the ocean bottom interface. The conversion process is already underway under FY89 ONR seed funding. By short-range, we mean 3D dimensions of the order of 50x50x50 wavelengths. A summary of the computer algorithms available for this project is given in Table 1.

Similarly, we have existing models for sediment deposition and rock properties which together generate realistic geological models for the bottom/subbottom interface. By realistic, we mean that the scales of heterogeneities and material properties are consistent with geological constraints and experimental observations.

Both geological and seismic-acoustic models are run on our in-house Ardent Titan-II supercomputer. This machine is wholly owned by the Department of Geophysics thus providing a powerful in-house platform for the numerical work with rapid access to results. Our version of the Ardent has two CPU's each with vector processors which can sustain 10 Mflops. Estimates for the CPU time needed for problems that will be addressed in this project are given in Table 1. The preliminary results summarized below in Section 2.1 and in Table 1 indicate that our approach is an accurate way of examining both 2D and 3D scattering effects.

There are two major issues addressed in the numerical approach used: First, an accurate representation of physical properties of the geological model - such as anisotropy and attenuation of unconsolidated sediments, and second, an adequate way of modeling the seismic response to geometry of the water sediment interface and the small scale volumetric heterogeneities.

<u>Accurately Modeling the Sediments.</u> To describe the scattering interaction, one must parameterize the properties of the ocean bottom and subbottom with elastic moduli, attenuation factors (Q), density, and a geometric description of the heterogeneities including the rough interface. SedSim (Harbough, Dept of Applied Earth Sciences) is a numerical model for constrained sedimentological deposition of sand-clay concentrations representative of young marine sediments. Multiple depositional episodes can be simulated to form the 3D geometry, i.e., structure, of beds, laminae, and ponds. The scales of heterogeneities generated are self-similar so that the models are dimensionless. Also, for several years and with continuous ONR support, our Rock Physics Group has been developing seismic velocity and Q models for sedimentary mixtures of sand and clay. Based on both field and laboratory results, these models describe relationships between seismic velocity, density, attenuation, porosity, permeability, mineralogy, and confining pressure for suspended and loosely consolidated granular materials. Together, the depositional model and the seismic sediment properties models provide for the first time the necessary tools for creating geologically realistic sedimentary models for the ocean bottom/subbottom interface.

<u>Accurately Modeling the Acoustic Scattering.</u> Both finite difference and Fourier algorithms provide us with fast and computer efficient methods to evaluate spatial operators for

material properties that are adequately sampled on regular grids (Kosloff 1973). The Fourier algorithm tends to provide a more accurate evaluation of spatial operators for models with rapidly varying properties as in the case of the SedSim model investigated to date. Nevertheless, both algorithms deliver excellent accuracy for four or more grid points per wavelength. In our existing codes, both finite difference and Fourier algorithms are implemented with a central difference method for time integration.

Modeling of attenuation is performed using a pseudo spectral algorithm (Kosloff 1988, Samec 1987, Carcione 1987). The attenuation mechanisms are modeled by a set of relaxation mechanisms (two or more) therefore providing a means to shape the variations of the quality factor (Q) with frequency according to experimental results, and still yielding a causal attenuation mechanism.

Numerical modeling of regularly sampled data with the algorithms mentioned above results in well known artifacts for curved interfaces. Such artifacts are numerically overcome by using finite element techniques which allow an accurate description of both interface geometries, as well as an explicit formulation of boundary conditions. To properly handle both the geometrical features of the sea floor and the scales of heterogeneities, an explicit-implicit finite element (Hughes 1983) algorithm has been implemented that allows the handling of a large number of elements (35,000) in acceptable Ardent computation time. The performance of this algorithm is further improved by the use of an hybrid Finite-element/Finite-difference algorithm that both allows a careful description of the geometrical features of the ocean bottom as well as a fast and accurate numerical modeling of the subbottom volume heterogeneities.

2.2 Preliminary Results

(The results shown here were obtained in part in early July under the auspices of anticipated FY89 ONR funding.) The SedSim depositional simulator was run to create a 3D geological model for the sediments. In Fig. 1 left, we illustrate three 2D slices from the 3D SedSim model. The water column is shown in white overlying the sediments built up on basement rock. The rock properties model was then applied to compact the sediments and assign values for density, compressional and shear wave velocities. In Fig. 1 right, we show the elastic properties for SedSim slice A. Note the fuzzy shear transition zone (B right) near the water-sediments interface. The compressional wave reflectivity is shown in Fig. 1C right. Reflectivity spectra through this model are shown in Fig. 2 to illustrate the self-similar power law distribution of reflectors, seen by acoustic waves, in the heterogeneities generated by SedSim.

In the next two figures we display the scattered wavefield for simulated experiments run over the SedSim model. Fig. 3 is acoustic; Fig. 4 is elastic. The experiment has an array of detectors collinear with an isotropic source in the water above the sediments. In these and subsequent seismograms, we plot the detected displacement in water rather than the pressure; this results from our seismic applications, a result which will be changed as part of our FY89 research. In both figures 3 and 4, the direct wave is present on the horizontal detectors only - as it should be because the displacement detectors are horizontally collinear with with the source. The elastic scattering wavefield (Fig. 4) is considerably more complicated than the acoustic wavefield (Fig. 3), particularly in the later arriving events where the shear waves contribute most. By subtracting the acoustic and elastic seismograms, we can highlight the energy which contributes to the reverberation which is neglected by the acoustic formulation. This difference seismogram is shown in Fig. 5. A large part of the direct wave is annihilated by the subtraction, but near grazing angles the acoustic and elastic fields differ most significantly.

Clearly the elastic formulation is needed to accurately model the near grazing angle phenomena so important to the reverberation problem. This simple subtraction illustrates the

importance of treating elastic properties and qualitatively describes the particular role played by shear waves generated within the sediments. Furthermore, because the converted shear related energy reentering the ocean tends to be less coherent than other arrivals, it is likely to contribute significantly to the reverberations. These models were run without attenuation, which will further affect the relative magnitude of shear contribution.

In Fig. 6, we display a constant-offset seismogram - where the source and detector are set a fixed horizontal distance apart and moved laterally across the sediments. This geometry highlights the effects of lateral heterogeneities as sensed acoustically. In Fig. 6A, the offset is only 50 meters thus giving a near vertical incidence backscattered image of the sediment structure. Note the incoherence of the returns. In Fig. 6B, the horizontal offset is 350 meters, thus approaching grazing incidence forward scattering. In this case the reflections from the sediments appear more coherent, an effect due to lateral homogenization introduced by the near grazing propagation.

Finally, in Figure 7, we show a result for attenuation and anisotropy although modeled here only in a homogeneous medium. This result is included simply to illustrate the kind of effects which give rise to Q anisotropy and to document the ability of our codes to include Q and anisotropy both of which will be used in the ocean bottom research.

40 X 40 (X40) Wavelengths with 1000 Time Steps

Spatial Dimensions	2	2	2	3	2	2 - 2.5	2 - 2.5
Spatial Operator	Finite difference	Finite difference	Fourier method	Finite difference	Fourier method	FE implicit -explicit	Hybrid FE-FD
Time domain integration	Central difference	Central difference	Central difference	Central difference	Pseudo Spectral	Predictor-Corrector	Predictor-Corrector
CPU time (mins)	1	2.5	16	480	32	71	3 -71
Core (MBytes) Precision	2 single	6 single	6 single	72 single	36 double	52 single	6-52 dynamic, single
Perf. Mflops Ardent Titan-II	11	11	7	10 (swap)	6.5	4.6	4.6-11
Comments	Acoustic	Elastic	Elastic	Elastic	Q factor Anelastic	Geometrical features	Faster than straight FE
Optimization							
Vector	X	X	X	X	X	X	X
Parallel	X	X	X	X	X		

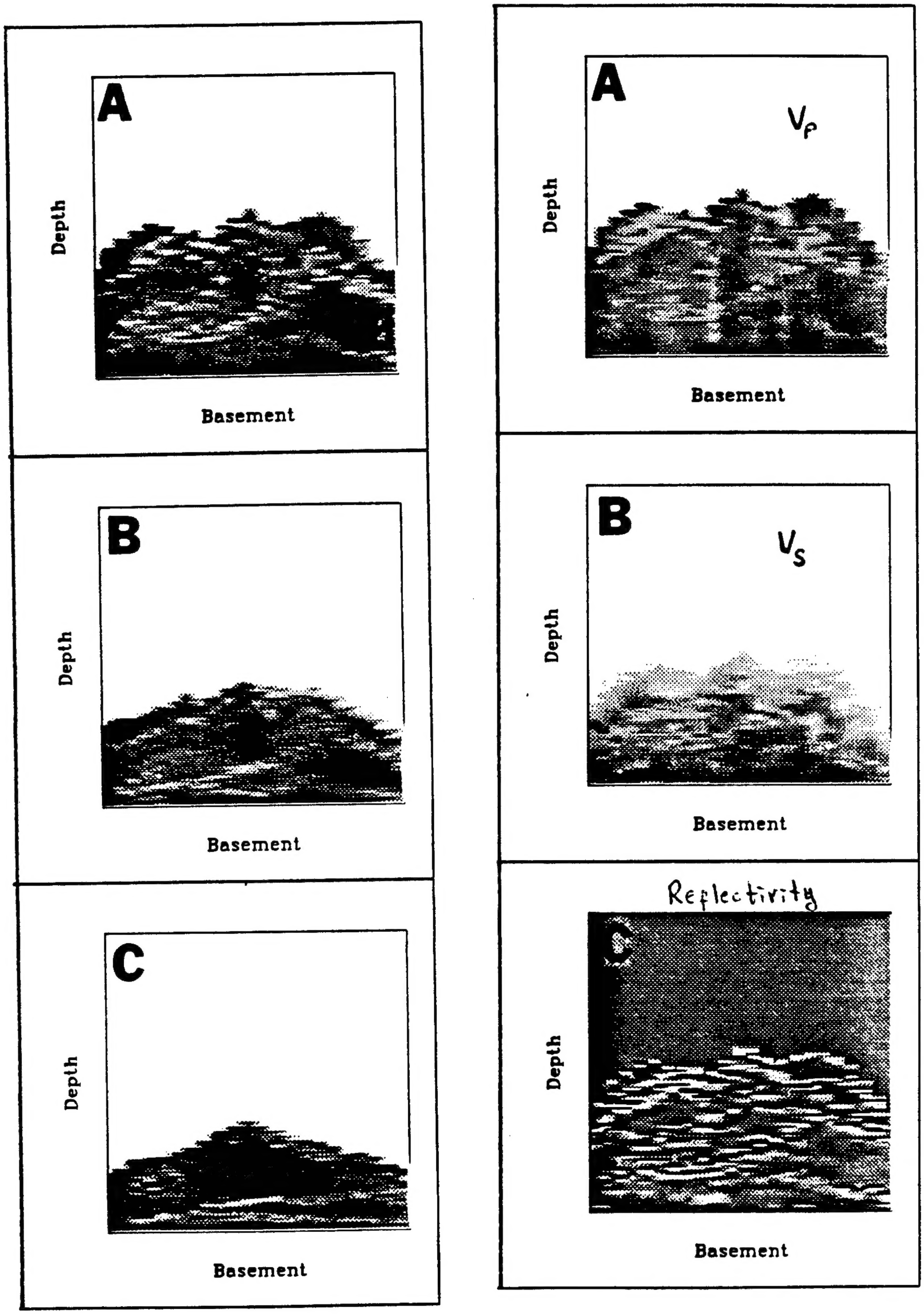


Figure 1: Sedsim model : Displayed on the left are three slices extracted from the Sedsim three dimensionnal sediment model. From **A** to **C**, the slices are extracted further from the sediment input location (further from the coast line), which explains the thinning of the sediment layer. Displayed on the right are the compressional velocity (A), the shear velocity (B), and the reflection coefficient (C) inferred from sediment bulk composition.

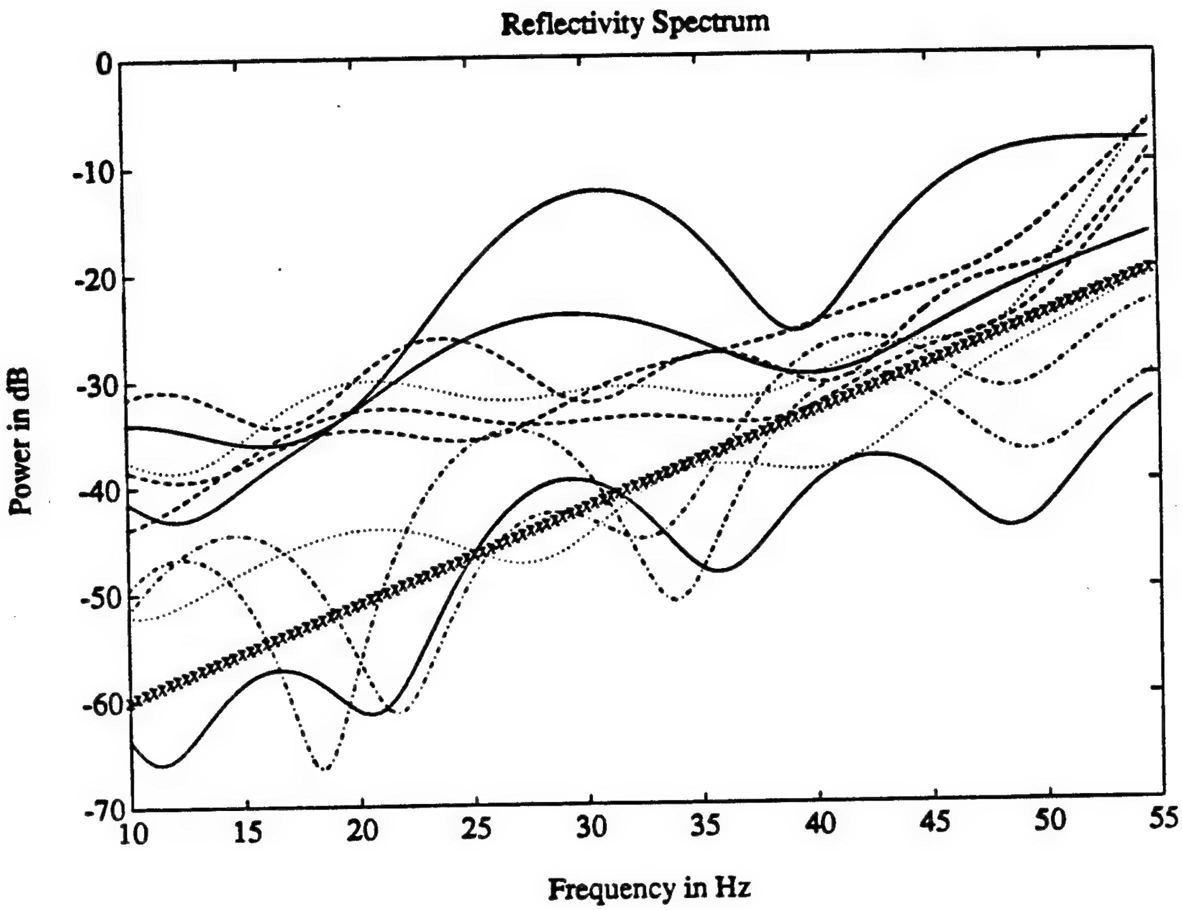


Figure 2: Frequency distribution of the the reflectors as seen in Fig. 1c: This graph presents the power spectrum of the reflectivity as a function of the two way travel time. The straight line underlines the proportionality of the power spectrum to $f^{0.8}$ which is consistent with the data inferred from seismic and well log data in Gulf coast sediments.

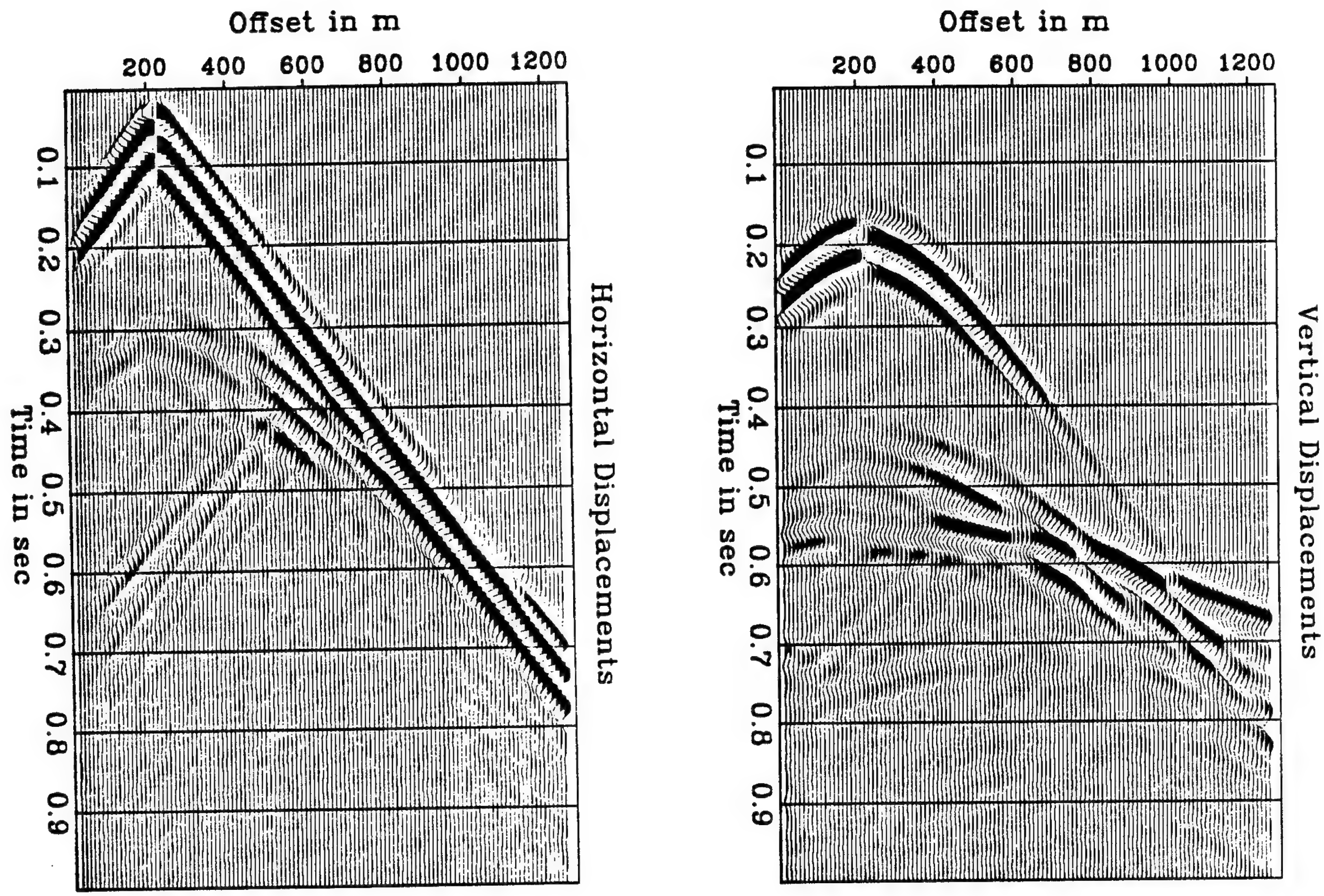
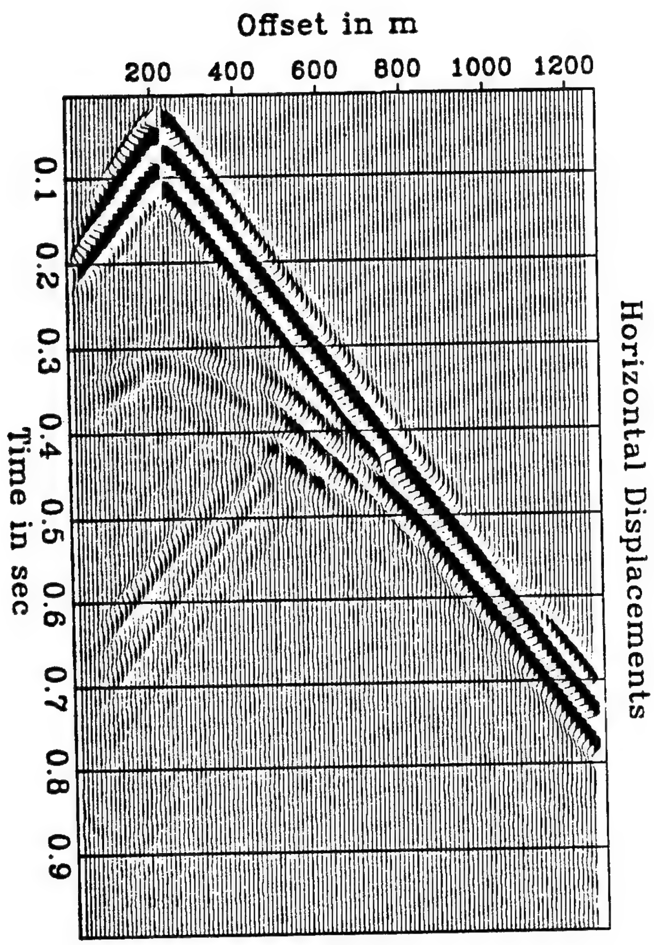


Figure 3: Common shot gather for the acoustic modeling : a) Horizontal component of the displacements, b) Vertical component of the displacements.



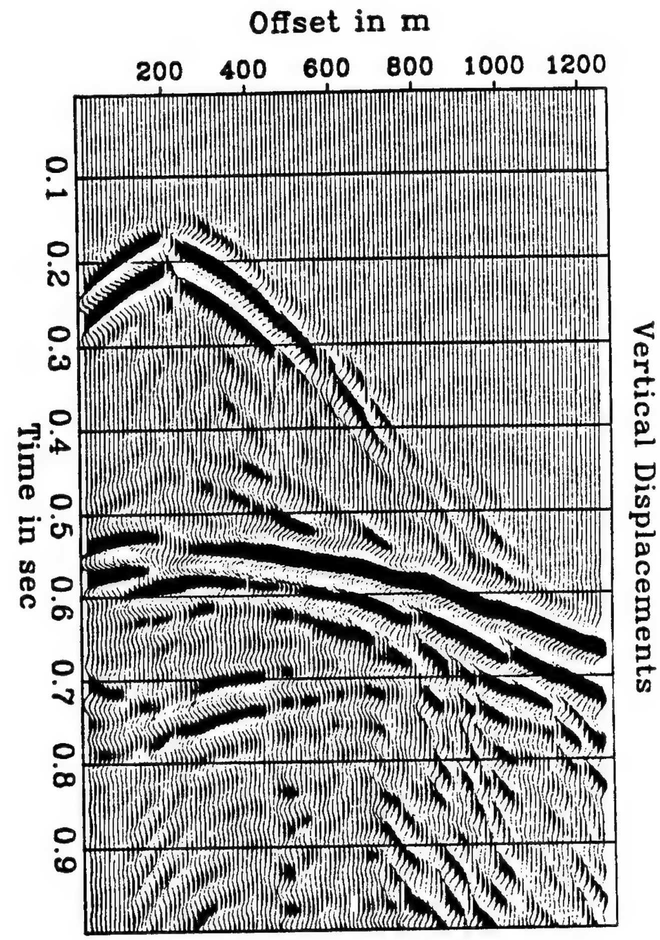


Figure 4: Common shot gather for the elastic modeling : a) Horizontal component of the displacements, b) Vertical component of the displacements. Note here the importance of the shear waves related events.

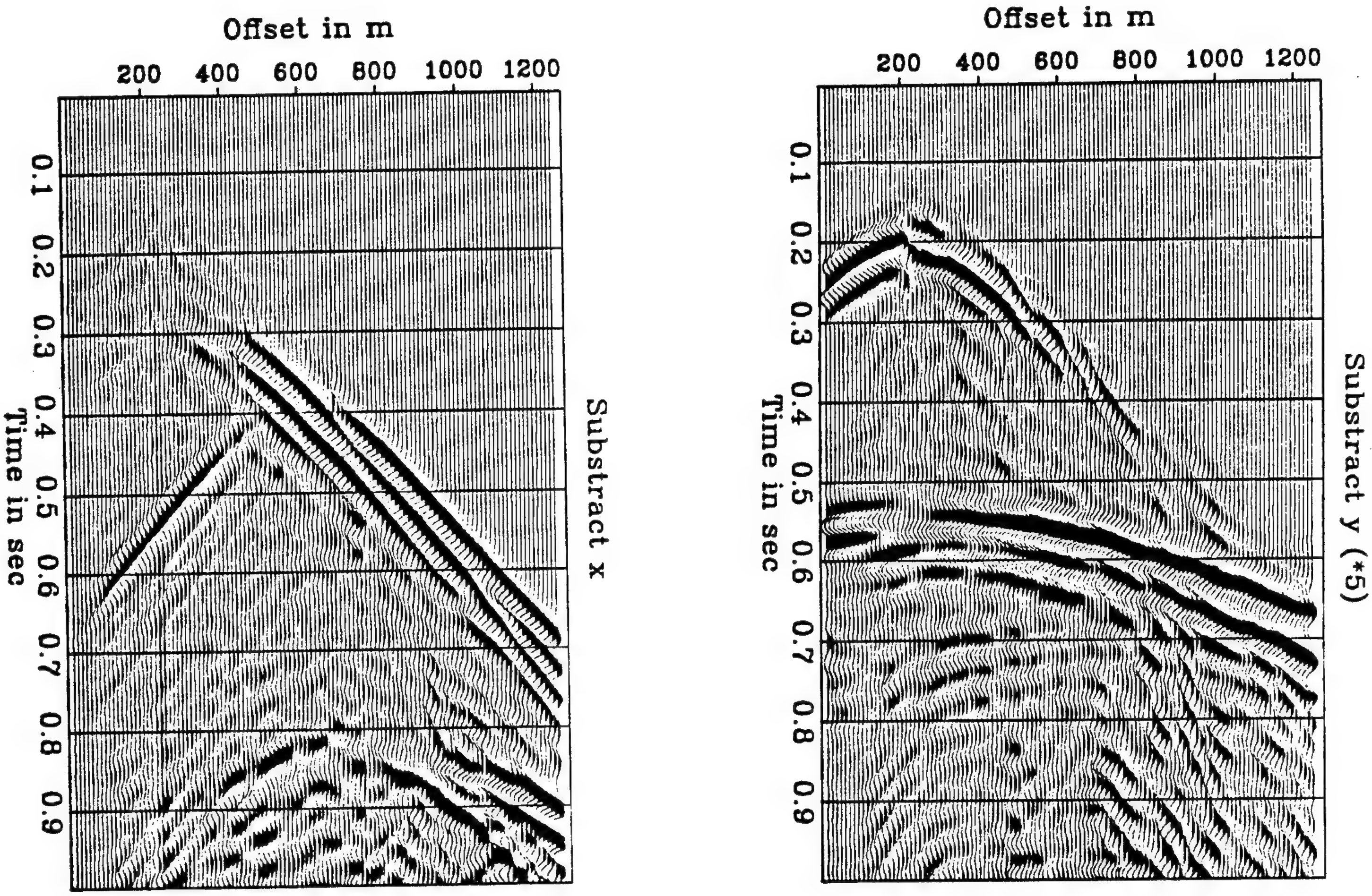


Figure 5: Straight amplitude difference between the models presented in Fig. 3, and Fig. 4.

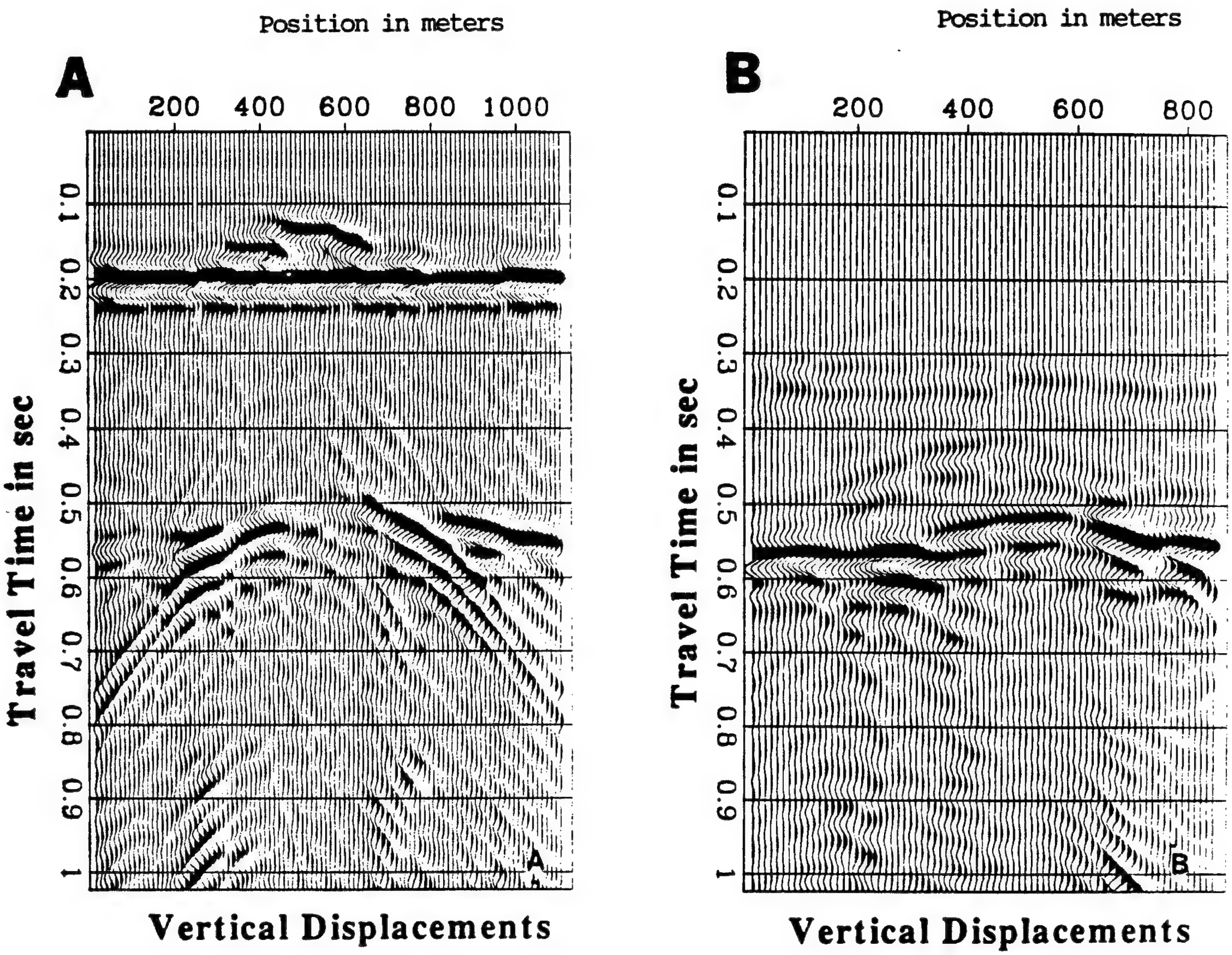


Figure 6: Constant Offset sections : a) 50 meters offset, b) 350 meters offset.

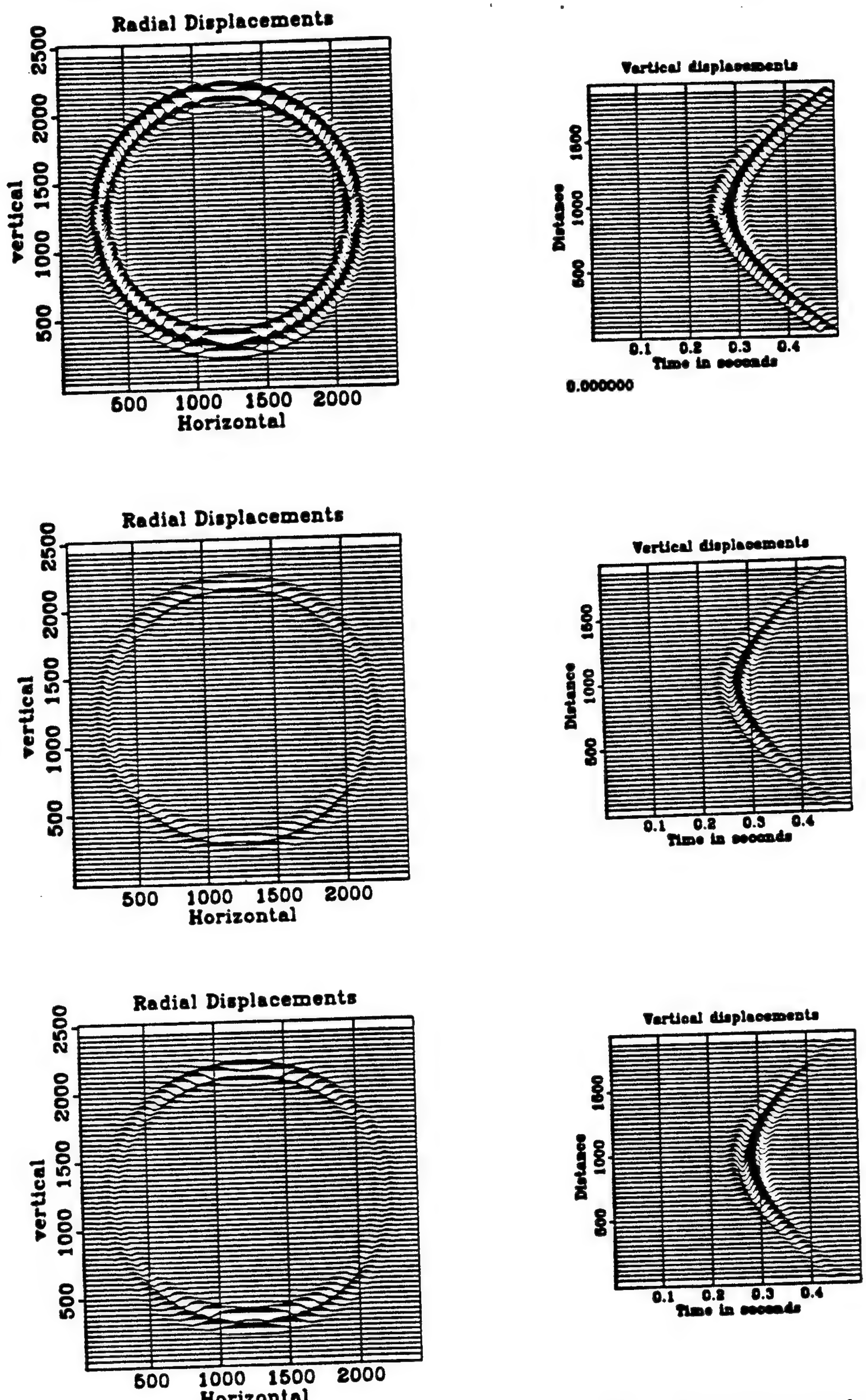


Figure 7: Modeling of anelastic homogeneous medium : On the left are the snapshots of the wavefield generated by an explosive point source. On the right are the traces recorded on a receiver array placed on top of the model. From top to bottom : 1) Isotropic elastic medium, 2) Anelastic isotropic medium with $Q = 20$, 3) Anelastic medium with anisotropic quality factor. In this last case Q varies from 500 along the vertical to 20 along the horizontal.

3.0 Proposed Activities and Schedule For FY90 and FY91

We include the activities proposed for the FY89 research program in order to show the continuity with proposed FY90 and FY91 research. A time line schedule of activities is shown in Figure 8.

FY89: Activities during FY89 is largely investigatory, aimed at identifying the important short-range scattering questions for long-term study.

1. Use 2D SedSim to generate examples of the lateral and depth variations representative of the scales of heterogeneities found in young marine sediments.

2. Use existing rock physics models to include compaction in the SedSim sediments and assign seismic values for compressional and shear velocities, density, porosity, and permeability.

3. Assess the numerical accuracy of the 2D seismic code for modeling the shear transition zone (shear velocities approaching zero) at the ocean bottom/subbottom interface.

4. Initiate study of the role of converted shear waves and attenuation on the reradiation of subbottom scattered energy back into the ocean column.

5. Determine, using SedSim models, the parameters needed to effectively characterize the scattering, e.g., velocity, attenuation, density, or impedance; determine the media parameters which control the magnitude of the water /sediment wave interaction.

6. Examine the scales of heterogeneity in 2D and 3D which dominant the short-range scattering interaction.

FY90: We suggest that the 2D seismic-acoustic models will not provide good quantitative representations of the scattering primarily because 3D geological models are often microscopically anisotropic often with strong lineations perpendicular to the direction of depositional flow. Such anisotropic features are well represented in the SedSim models. This year's activities include:

1. Expand 2D elastic simulations started in FY89 to 3D anelastic simulations. This requires improved development of attenuation models for sediments using lab and field data for control. Refinement and optimization of the seismic-acoustic simulators will continue with specific focus on the hybrid finite element- finite difference algorithm.

2. Begin modeling the canonical reverberation experiment with actual source and detector geometries, frequencies, and beamwidths for source and detector arrays. Analysis tools for beamforming point source and point detector simulation data will be be developed.

3. Using the footprint formed by the source and detector array as a guide for scale, we will begin the development of techniques for partitioning the scattered wavefield into deterministic and stochastic components. An expected output of this activity is a statistical description of the differential scattering cross-sections for elastic scattering off the sediments. Results will be compared with analytic treatments of scattering by rough surfaces and random media.

FY91: To this point, we have developed the basic simulation and analysis tools for short-range scattering. Research will continue on improving and refining these tools. A specific activity for FY91 will be to simulate the natural lab.

1. Complete development of sediment properties for velocity, attenuation, density, porosity, and permeability and the respective anisotropies in sedimentary mixtures.

2. Finalize the seismic-acoustic modeling suite for 3D anelastic media.

3. Develop methods for embedding the short-range scattering results into the long-range reverberation models. This will be done with outside researchers yet to be identified who are working on the long-range reverb problem.

4. Create and run specific 3D deterministic simulations for a site within the natural laboratory.

4.0 Deliverables

Several ONR funded research groups will be addressing the short-range scattering problem. It is important that each group compare results so that a final assessment can be made for the strengths and weaknesses of the many different modeling schemes implemented. To that end, we propose to make available to the scattering community a 3D SedSim generated model with complete anelastic properties for the sediments, including realistic compressional and shear wave velocities, density, permeability, porosity, and eventually compressional and shear wave attenuation factors. This model with have both topographic roughness at the sediments' interface and volumetric distributed heterogeneities.

The major deliverable shall be a suite of computer codes capable of modeling the short-range scattering of seismic-acoustic waves for three-dimensional anelastic media. In addition to these basic wave equation solvers, we will have methods and codes for modeling the actual source and detector geometries used in the reverb experiment, that is, beamformed source and detectors arrays. Finally, we will provide methods and codes for analyzing the simulated results; these will include codes for calculating differential scattering cross-sections and statistical properties of simulated scattering seismograms and acoustograms.

Schedule of Activities

FY89 3rd Q	FY90 4th Q	FY90 1st Q	FY90 2nd Q	FY90 3rd Q	FY91 4th Q	FY91 1st Q	FY91 2nd Q	FY91 3rd Q
Port SedSim to Ardent Adapt seismic codes to Ocean acoustics								
Assess codes for shear transition zone and study converted shear waves								
Correlate scattering results with isovalues of SedSim model								
Examine scale dependence of scattering								
	Incorporate better models for attenuation Expand all seismic-acoustic simulations to 3D							
		Begin statistical characterization of scattered fields						
				Develop of software for beamforming point source/detector simulation results				
				Model canonical reverb experiment				
					Complete Codes for sediment material properties			
						Complete final suite of seismic-acoustic modeling codes for 3D anelastic scattering		
						Begin development of methods for embedding short-range results into long-range reverb models		
							Create rock/sediments model & simulate natural laboratory site	

Figure 8

BUDGET

	10/1/89 - 9/30/90	10/1/90 - 9/30/91
A. SALARIES AND WAGES		
Amos Nur, P.I., .5 months, calendar year	$3,900	$4,000
Jerry Harris, Co-P.I., .5 months, calendar year	3,900	4,000
Postdoc research fellow, 5 mo's, 100% time	13,000	13,000
Graduate students (one first year, two second year) 50% academic yr., 100% summer	14,000	28,000
TOTAL SALARIES AND WAGES	$34,800	$49,000
B. BENEFITS		
9/1/89 - 8/31/90 @ 27.8%	$9,699	
9/1/90 - 8/31/91 @ 28.6%		
9/1/91 - 8/31/92 @ 29.3%		$14,043
TOTAL SALARIES AND BENEFITS	$44,499	$63,043
C. TRAVEL		
Two trips: east coast & west coast	$2,000	$3,000
D. EXPENDABLES		
Computing costs		
200 hours @ $50/hour	$10,000	
300 hours @ $50/hour		$15,000
Publication costs		
25 pages @ $100/page	2,500	
50 pages @ $100/page		5,000
TOTAL EXPENDABLES	$12,500	$20,000
E. TOTAL DIRECT COSTS	$58,999	$86,043
F. TOTAL INDIRECT COSTS 74% of MTDC	$43,659	$63,672
G. TOTAL COSTS	$102,658	$149,715
H. TOTAL TWO-YEAR COSTS	$252,373	

STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305-2215

DEPARTMENT OF GEOPHYSICS
School of Earth Sciences

February 20, 1990

Mr. Marvin Blizard
bct #1, Rm 633
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5000

Ref: ONR grant with a start date of 01-01-90 for two years @ $252,373.

Proposal # 8942--0169 Procurement # 4258043---01.

Title: Ocean bottom/subbottom seismic-acoustic scattering with realistic rediment properties.

Principal Investigators: Jerry M. Harris/Amos Nur

Department: Geophysics

Dear Mr. Blizard:

As per our conversation today, this is a request for a budget modification. Attached please find a modified budget for the above mentioned grant. The modification reflects a more realistic use of our proposed dollar expenditure. This request to rebudget the salary portion of the grant will **not** effect the total cost of the project.

Sincerely,

Margaret Muir

Margaret Muir
AA to Amos Nur, Chairman and Professor
Geophysics Department.

encl: revised budget.
cc: Stephanie Mitchell, Contracts officer, ONR.
Lilly Ryan-Culclager, Jerry M. Harris

MODIFICATION February 1, 1990

	ONR BUDGET:	01/01/90.	01/01/91.
A.	SALARIES AND WAGES		
	Jerry Harris, PI., .05 months/calender	3,900.00	4,000.00
	Amos Nur, CO PI., .05 months/calender	3,900.00	4,000.00
	Postdoc research fellow, 5 mths @ 100%	13,000.00	14,000.00
	Graduate students, 50% academic yr. (2 first year, 3 second year) 100% summer.	22,000.00	39,000.00
	Secretary	750.00	800.00
		43,550.00	61,800.00
B.	BENEFITS @ 1st year: 8 mths @ 27.6% 4 mths @ 28.3% 2 year: 8 mths @ 28.3% 4 mths @ 29.6%	12,119.97	17,242.20
	TOTAL SALARIES AND BENEFITS	55,669.97	79,042.20
C.	TRAVEL (National meetings).	2,000.00	3,000.00
D.	SERVICES & EXPENDABLES. Office/lab supplies, xeroxing, mailing.	881.33	2,067.35
E.	TOTAL DIRECT COSTS	55,669.97	84,109.55
F.	INDIRECT COSTS @ 1st. year: 8 mths @ 74%, 4 mths @ 78% 2nd. year: @ 78%,.	44,106.69	65,605.45
	YEARLY TOTALS:	$102,657.99	$149,715.00

TOTAL PROJECT COST: $252,373.

6.0 Other Anticipated Support

There are several active on-going projects within the Department of Geophysics in rock physics and seismic modeling. In general, these projects encompass the development of seismic modeling codes in combination with research in seismic inversion, data processing, and data acquisition. Most are funded by the oil and gas industry. In addition, Professor Nur has existing DOE and ONR funding for rock properties research. Professor Harris has support ($940k with Nur) from the Gas Research Institute for cross-well seismic and anticipates support ($20k) from British Petroleum for interactive seismic imaging research.

		Other Funding - Nur		
Project/grant	Funding Agency	Period	Funding	PI time
				Academic yr.
Physical Properties	ONR	10/1/89-9/30/90	75k	8%
of Marine Sed.				
Rocks with fluids	DOE	10/1/89-9/31/90	175k	8%
Block tectonics	NASA	3/1/89-2/28/90	105k	8%
Rock Physics &	GRI	10/1/89-10/31/90	115k	8%
Cross-well Imaging	(with Harris)	1/1/89-12/31/89	940k	8%

7.0 Qualifications

7.1 Facilities and Equipment

Computing facilities: We have in operation an ARDENT Titan graphics supercomputer, which provides the intense numerical computing needs for the project. We also have three 4 SUN workstations and a Versatec color plotter available for use to this project. The department has a CONVEX C1 supercomputer, which is part of the Stanford Exploration Project (SEP). Finally, we have direct access to three CRAY computers: One through Stanford university to the San Diego supercomputing center; another through our DOE grant to Lawrence Berkeley Laboratory's CRAY; and the third through Chevron to their supercomputing facility at LaHabra.

We propose to use the Ardent for the main supercomputing platform in this study. All of the codes described above are implemented on this machine. With floating point speed of approximately one fifth the Cray, the Ardent provides much better turn-around and 3D graphics for easy analysis an interpretation of results. The Ardent costs approximately $50/hr for the complete resource including, CPU time, disk storage, operations, etc. or approximately 1/40 the cost of remote Cray time.

7.2 Personnel and Resumes

Dr. Jerry Harris (see enclosed CV) received the Ph.D. from the California Institute of Technology in 1980 in electrical engineering. He is an expert in the area of signal processing based on wave physics and specializes in single-well and cross-well seismic imaging. During the past 4 years, he was development manager of British Petroleum's cross-well seismology

program and was responsible for its advance over all other such programs in industry. He joined the Department of Geophysics as Associate Professor in the fall of 1988.

Dr. Amos Nur (see enclosed CV) received the Ph.D. in geophysics from the Mass. Inst. of Technology in 1969. He is an expert in rockphysics and rock mechanics and specializes in the relation between seismic and reservoir properties of rocks. He has published over 150 refereed papers, resulting from funding over the past 15 years by the Department of Energy, NSF, GRI and for the last 11 years by a consortium of oil and oil field service companies. He is professor of geophysics and also chairman of the department.

7.3 CVs and Bibliographies

Jerry M. Harris

Associate Professor of Geophysics, Stanford University

Year and Place of Birth:

1951; Sardis, Mississippi

Education:

B.S., 1973; Electrical Engineering, University of Mississippi
M.S., 1974; Electrical Engineering, California Institute of Technology
Ph.D., 1980; Electrical Engineering, California Institute of Technology

Professional Positions:

Staff Engineer, Communications Satellite Corporation; 1974-77.
Research Specialist, Exxon Production Research Company; 1980-84.
Staff Geophysicist, Standard Oil Production Company; 1984-1988.
Associate Professor of Geophysics, Stanford University; 1988 - present.

Professional Activity:

Member, Society of Exploration Geophysics
Member, Institute of Electrical & Electronics Engineers
Member, Society of Petroleum Engineers
U.S. Delegate, International Consultative Committee on Radio (CCIR), Geneva; 1976.

Research Interests and Activities:

Seismic and electromagnetic wave propagation
Adaptive high resolution signal processing
Wave equation imaging and inversion
High resolution experimental techniques

Honors and Awards:

Corning Fellow, CalTech; 1974.
Academic Reward for College Scientists, CalTech; 1978.
Hughes Fellow, Caltech, 1979-80.
Member, Engineering honor society, Eta Kappa Nu & Tau Beta Pi.
Outstanding Graduate Achievement Award, University of Mississippi; 1982.

J. M. Harris' Recent Publications

D. J. Fang and J. M. Harris, 1979. Precipitation Attenuation Studies Based on Measurements of the ATS-6 20/30 GHz Beacons at Clarksburg, MD, IEEE Trans. Antennas Prop., vol. AP-27, January 1979, pp 1-11.

W. Wells and J. M. Harris, 1981. Multiple Scattering of Collimated Irradiance, J. Optical Society of America, vol. 71, no. 3, March 1981, pp 243-249.

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G. A. McMechan, J. M. Harris, and L. Anderson, 1987. Cross-well tomography for strongly variable media with application to scale model data, Bulletin, Seismological Society of America, Vol. 77, No. 6, pp. 1945-1960.

J. M. Harris and A. G. Ramm, 1988. Two Dimensional Inversion of Well-to-Well Data, Appl. Math. Lett., Vol. 1, No. 2, pp. 127-131.

L. Z. Hu, G. A. McMechan, and J. M. Harris, 1988. Acoustical pre-stack migration of cross-well data, Geophysics, Vol. 53, No. 8, pp. 1015-1023.

J. M. Harris, 1989. Point-to-Point Born inversion of spherical wave data, to appear in Geophysics.

VITAE: AMOS M. NUR

Amos M. Nur, Born February 9, 1938.

Position:

Professor of Geophysics, Chairman of the Department of Geophysics.

Education:

B. Sc., Geology, Hebrew University
Ph.D., Geophysics, M.I.T. Cambridge, Mass. 1969.

Professional Positions:

Research Associate in Geophysics, MIT. 1969-70.
Assistant Professor of Geophysics, Stanford University, 1970-74.
Associate Professor of Geophysics, Stanford University, 1974-79.
Visiting Professor, Weizmann Institute of Science, 1974-77.
Professor of Geophysics, Stanford University, 1979-
Chairman, Department of Geophysics, Stanford University, 1986-

Professional Activity:

Member, Lunar Sample Review Board, 1972-73.
Associate Editor, Journal of Geophysical Research, 1974-77.
Member, Committee on Seismology, National Research Council, 1974-77.
President, Tectonophysics Section, AGU, 1976-77.
Member, National Science Foundation Earth Sciences Advisory Board, 1974-77.
Member, National Academy of Science Earthquake Delegation to the Peoples Republic of China, 1976.
Delegate, Japan-US. Earthquake Prediction Symposium, Tokyo, 1977.
Director, Stanford Rockphysics and Borehole Geophysics Project (SRB) 1977-
Associate Editor, Tectonophysics, 1979-1987.
Member and Chairman, Earth Sciences Review Panel, LBL, 1980-81.
Member, Day Medal Committee, G.S.A, 1981.
Member, Bucher Medal Committee, A.G.U. 1981.
Member, Hydrocarbon Research Drilling Committee, NRC, 1987-88.
Invited speaker at 1988 SEG Annual Meeting Research Symposium.
Member, AGU Macelwane award committee, 1988.
Member, advisory board, Department of Earth Science, Purdue University, 1988.

Honors and Awards:

Research Fellow, A.P. Sloan Foundation, 1972-74.
J. B. Macelwane Award, American Geophysical Union, 1974.
Mellon Fellowship, Stanford University, 1974-75.
Newcomb Cleveland Prize, A.A.A.S. 1975.
Fellow, American Geophysical Union, 1976.
Fellow, Geological Society of America, 1980.
University Fellow, Stanford University, 1980.
Fellow, Sackler Institute, Tel Aviv University, 1985-
Wayne Loel Professorship of Earth Sciences, 1988.
Invited Snider Lecturer, Erindale College, University of Toronto, Canada, 1988.

Bicentennial Fellow, Universidad de los Andes, Merida, Venezuela, 1988.
Visiting Professor, University of Tokyo and ERI, 1988.

Professional Societies:

American Geophysical Union.
Geological Society of America.
Society of Exploration Geophysicists.
Seismological Society of America.
American Association for the Advancement of Science.
Society of Petroleum Engineers.
New York Academy of Sciences.

PUBLICATIONS: AMOS NUR

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ber. pp. 450-458.

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